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PARASITOIDS OF BLACK SCALE IN CALIFORNIA: ESTABLISHMENT OF *PROCOCCOPHAGUS PROBUS* ANNECKE & MYNHARDT AND *COCCOPHAGUS RUSTI* COMPERE (HYMENOPTERA: APHELINIDAE) IN OLIVE ORCHARDS

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Abstract.—A survey of the parasitoid species of black scale, *Saissetia oleae* (Olivier), in California central valley olive orchards revealed that two recently imported parasitoids, *Prococcophagus probus* Annecke & Mynhardt and *Coccophagus rusti* Compere, have become established. These South African parasitoids were released from 1979 to 1983. During the release period, neither parasitoid was recovered. However, subsequent to the release, surveys of distribution of these species revealed that both had become established. In the first survey (1984–1987), 23 commercial olive orchards located in Tehama, Glenn, Madera, and Tulare Counties, were sampled. A second survey (1988–1990) included seven olive orchards located in Tehama and Madera Counties, and black scale infestations on selected ornamental olive and oleander plants in Tehama, Colusa, Sutter, Glenn, and Butte Counties. *Prococcophagus probus* and *C. rusti* were reared from black scale infested olive and oleander plants in Tehama County. Recovery of these species, over the three years after the last release, provides evidence of their establishment in the Sacramento Valley.

Key Words.—Insecta, Aphelinidae, *Prococcophagus, Coccophagus,* Homoptera, *Saissetia oleae,* olive, biological control

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Black scale, *Saissetia oleae* (Olivier), believed native to South Africa (De Lotto 1976), is found throughout the tropical and subtropical regions of the world. It is a very polyphagous species with a host range that includes such common plants to California as oleander (*Nerium oleander* L.), pepper tree (*Schinus molle* L.), coyote brush (*Baccharis pilularis* Wolf), and toyon (*Heteromeles arbutifolia* Lindahl) (Argyriou 1963). In California, *S. oleae* has been a pest of olive (*Olea europaea* L.) and *Citrus* spp. since the 1880s. As a result of its wide host range and high reproductive rate, the scale has spread throughout California and is ubiquitous in the state's central valley olive orchards, resulting in frequent infestations.

Black scale is exotic to most olive growing regions and has been the target of numerous classical biological control programs (Bartlett 1978). Studies of population dynamics in the Mediterranean region have attributed significant scale mortality to natural enemies (Argyriou & Katsoyannos 1976, Monaco 1976, Paraskakis et al. 1980, Roberti 1981). In California, biological control programs against *Saissetia oleae* began in 1891 and natural enemies have been imported since from Asia, Africa, Australia, Central and South America, Europe, and the Middle East (Bartlett 1978, Kennett 1986). Parasitoid importation and establishment in California resulted in relatively successful control of black scale on ornamentals and citrus in coastal regions. However, parasitoid establishment in the central valley

has not been as successful. Over 50 natural enemies of black scale have been introduced in California and less than 15 have become permanently established in the central valley (Table 1).

Establishment of black scale parasitoids is best understood in light of the population dynamics of their host. Seven black scale stages can be differentiated from egg to adult (Argyriou 1963), although most black scale parasitoids are specific to only two or three consecutive host stages (Smith & Compere 1928, Compere 1940). Thus, it is difficult for some parasitoids to become established where scale development is univoltine and synchronous because of the long periods in which suitable host stages are not commonly found. Due to harsh climate in the central valley, black scale development there is more synchronous than in coastal California (Daane 1988). For example, *Metaphycus lounsburyi* (Howard) is abundant at coastal locations but is rarely found in the interior valleys (Kennett 1986).

Further, many of the initial attempts to establish imported species of black scale parasitoids failed because of inadequate biological information (Bartlett 1978). For example, until the 1930s many primary parasitoids with obligatory male hyperparasitic habits were discarded as undesirable secondary parasitoids. Differences between parasitoid biotypes may also affect establishment. Panis & Marro (1978) showed that there were sufficient behavioral differences between two biotypes of *Metaphycus lounsburyi* (Howard) for them to be used in the same orchard for biological control.

We report here the establishment of two black scale parasitoid species, *Prococcophagus probus* Annecke & Mynhardt and *Coccophagus rusti* Compere, in olive orchards in the Sacramento Valley, where they were previously thought to have failed to become established. *Prococcophagus probus* was first released in California in 1979. *Coccophagus rusti* was first released in 1937 and was reported as established (Flanders 1952) in coastal locations, but not within the central valley. It was imported from South Africa again in 1978 and released in central valley olive orchards in 1980.

Materials and Methods

Parasitoid Release.—From 1979 to 1982, five parasitoid species were imported to California from South Africa. *Prococcophagus saissetiae* Annecke & Mynhardt, *P. probus, C. rusti, Aloencyrtus saissetiae* (Compere), and *Metaphycus inviscus* Compere were collected by S. Neser (South African Ministry of Agriculture) and sent to the quarantine station at the Division of Biological Control, University of California, in Albany. After release from quarantine, colonies were established in the insectary on black scale reared on oleander. From 1979 to 1983, 1180 *P. probus* (67% female), 3265 *P. saissetiae* (59% female), 535 *C. rusti* (88% female), 265 *A. saissetiae* (98% female), and 1352 *M. inviscus* were released at five olive orchards in the central valley (three orchards near Corning, Tehama County, one near Parlier, Fresno County, and one near Porterville, Tulare County) and on selected ornamental host plants of the black scale in the east bay region of the San Francisco Bay area (Alameda and Contra Costa Counties). Releases were concentrated in the fall of each year when the proper black scale host stages were most common.

Recovery Attempts.—During the parasitoid release period (1979–1983), olive twigs infested with black scale were collected at each release site in the fall and

Table 1. A partial list of introduced primary black scale parasitoids (source: Smith & Compere 1928, Bartlett 1978, Kennett 1986).

Species	Origin	Date introduced	Established
Aphelinidae			
Aneristus ceroplastae Howard	Taiwan	1933, 1952	no
Coccophagus anthracinus Compere	South Africa	1923	no
Coccophagus baldassarii Compere	Eritrea	1953	no
Coccophagus basalis Compere	Brazil	1958	no
Coccophagus capensis Compere	South Africa	1924	yes
Coccophagus caridei (Brethes)	Brazil, Argentina	1934, 1935	no
Coccophagus cowperi Girault	East Africa	1937	yes
Coccophagus eleaphilus Silvestri	Eritrea, Morocco	1953, 1953	no
Coccophagus hawaiiensis Timberlake	Taiwan	1951	no
Coccophagus japonicus Compere	Japan	1951	no
Coccophagus lycimnia (Walker)	Africa	1900s (accidental)	yes
Coccophagus lycimnia (Walker)[a]	Brazil, Argentina	1935, 1935	no
	Australia	1972	no
	Africa, Mexico	?	no
Coccophagus mexicensis Girault	Mexico	1956	no
Coccophagus nigritus Compere	Eritrea	1954	no
Coccophagus ochraceous Howard	Africa	1990s (accidental)	yes
Coccophagus eritreaensis Compere	South Africa	1925, 1937	no
Coccophagus rusti Compere	Kenya, Uganda	1937	yes
	South Africa	1932, 1981	yes
Coccophagus scutellaris (Dalman)	Africa	1900s (accidental)	yes
Lounsburyi trifasciatus (Compere)	South Africa	1924	yes
Prococcophagus saissetia Annecke & Mynhardt	South Africa	1978	no
Prococcophagus probus Annecke & Mynhardt	South Africa	1978	yes
Encyrtidae			
Aloencyrtus saissetia (Compere)	South Africa	1979	no
Anicetus annulatus Timberlake	Australia, Taiwan	1931, 1951	no
Coccidoxenus niloticus Compere	Kenya	1937	no
Diversinervus elegans Silvestri	Eritrea, Lebanon	1953, 1964	yes
Diversinervus smithi Compere	South Africa	1937	no
Encyrtus fuliginosus Compere	South Africa	1937	no
Encyrtus infelix Embelton	Hawaii	1921	yes
Metaphycus angustifrons Compere	Taiwan	1952, 1957	no
Metaphycus bartletti Annecke & Mynhardt	South Africa	1956	yes
Metaphycus citrinus Compere	Eritrea	1953	no
Metaphycus flavus (Howard)	Spain	1954, 1955	no
Metaphycus gilvus Compere	North Africa	1953	no
Metaphycus helvolus (Compere)	South Africa	1937	yes
Metaphycus lichtensiae Compere	South Africa	1958	no
Metaphycus lounsburyi (Howard)	Australia	1916–1918	yes
Metaphycus luteolus (Timberlake)	Mexico	1954, 1955	yes
Metaphycus stanleyi Compere	South Africa	1937	yes
Metaphycus zebratus Mercet[b]	Spain	1986	?
Microterys flavus (Howard)	Pakistan	1957	no
Microterys okitsuensis Compere	China, Japan	1951, 1952	no
Microterys saissetiae Compere	Uganda	1937	no
Microterys tricoloricornis (DeSoto)	Mexico	1956	no
Eupelmidae			
Lecanobius utilis Compere	Brazil, Argentina	?	yes

Table 1. Continued.

Species	Origin	Date introduced	Established
Pteromalidae			
Anysis saissetiae (Ashmead)	China, Pakistan	1924, 1957	no
Lecaniobus cockerelli Ashmead	West Indies	1913, 1915, 1940	no
Mesopelitita atrocyanea (Masi)	East Africa	1937	no
	South Africa	1957	no
	Mexico	1958	no
Scutellista caerulea (Fonscolombe)	South Africa	1901-1902	yes
Scutellista cyanea Motschulsky (red larval race)	Taiwan	1952	no

[a] *Coccophagus lycimnia* has been introduced from a number of countries, however, establishment of this species may be from accidental introductions prior to importation efforts.

[b] *Metaphycus zebratus* has been recovered continually since its release; documentation of permanent establishment is in progress.

spring of each year. Samples were brought into the laboratory and held in glass-topped sleeve cages from four to six weeks. Emerging parasitoids were collected three times a week and stored in 70% ethanol for later identification. These samples were taken as part of a central and northern California survey of black scale parasitoids that included a majority of the counties within the Sacramento and San Joaquin valleys and several coastal counties extending from Napa County to San Luis Obispo County (Kennett 1986). Nearly 70% of the samples were taken from urban and rural landscapes (olive; *Citrus* cultivars of grapefruit, orange; Modesto ash, *Fraxinus velutina* var. *glabra* Rehder; English holly, *Ilex aquifolium* L.), 20% from natural stands of native shrubs (coyote brush and toyon), and 10% from commercial olive orchards. Detailed results from these collections were reported by Kennett (1986).

From 1984 to 1987, a separate parasitoid survey was conducted in conjunction with a black scale population dynamics study on olive. All samples were taken from commercial olive orchards located in the central valley: seven orchards near Corning, Tehama County; one near Orland, Glenn County; one near Madera, Madera County; one near Parlier, Fresno County; and 11 near Lindsay, one near Strathmore, and one near Exeter, Tulare County. Included in this 23 orchard study were four of the five orchards that received the five imported black scale parasitoid species from 1979 to 1983. The release orchard in Porterville was removed in 1984 and is, therefore, not included in the survey. Likewise, the orchard in Parlier was removed in 1986 and data presented for parasitoids collection in 1987 does not include this orchard.

In each orchard sampled, except in Glenn County, collections were made every six to eight weeks. In the Glenn County orchard, samples were taken each fall and spring, when black scale parasitoids were most common. Olive twigs infested with black scale were collected and the scales were counted and recorded by developmental stage (first, second, third, pre-ovipositional, and adult) and condition (alive or parasitized). Infested twigs were placed in parasitoid emergence containers and held between 22 and 24° C for three to four weeks. Emerging parasitoids were collected and later identified.

From 1987 to 1989, seven orchards (five near Corning and two near Madera) were sampled, as described above, in each season of each year. An additional

survey for parasitoids on black scale infested olive and oleander plants was carried out in the spring of 1990 at seven sites in the Sacramento Valley: Red Bluff, Tehama County; Willows, Glenn County; Yuba City, Sutter County; Zamora, Yolo County; and Williams and Maxwell, Colusa County. Infested twigs were taken to the laboratory and parasitoids reared from the material as described above.

Results and Discussion

New Parasitoids.—Of the five parasitoid species released, only *P. probus* and *C. rusti* were found to have become established in central valley olive orchards. Establishment is defined here as parasitoid recovery three years after the last insectary release.

Prococcophagus probus was collected in 1985 and 1986 in two of the four original release orchards. Both orchards were located near Corning, Tehama County. *Prococcophagus probus* comprised 0.7% of the total parasitoids collected between 1984 and 1987 (Table 2). It was most commonly found in winter samples. In one orchard, *P. probus* comprised 8.0% ($n = 274$) and 1.1% ($n = 1235$), respectively, of parasitoids in November and December collections combined for 1985 and 1986. It was not recovered from any orchards in Glenn, Madera, or Tulare Counties, nor was it recovered from any orchards other than the original release sites. This suggests that *P. probus* did not disperse from the release areas.

Coccophagus rusti was collected from orchards near Corning, Tehama County from 1985 to 1987. The parasite was most commonly reared from third instar and pre-ovipositional stage scale, collected in spring and early summer months. Overall, this parasitoid comprised only 0.4% of the total parasitoids collected between 1984 and 1987 (Table 2). When considering release orchards only, the percent species composition of *C. rusti* was often higher. In one release orchard, *C. rusti* comprised 8.2% ($n = 205$) of the parasitoids reared from two collections in June and July, 1987. *Coccophagus rusti* was also recovered from two nonrelease sites: 1986, in an olive orchard over 1 km from the nearest release site, and 1990, in Red Bluff on oleander over 64 km from the nearest known release site. At the latter site, *C. rusti* accounted for 58%, the greatest number, of 19 parasitoids reared. This suggests that it either is increasing its geographic distribution or that a population has been present, without detection, in some central valley locations since the releases in 1937. Although *C. rusti* has not previously been found in the central valley, Flanders (1952) reported it to have been established in California at coastal locations, on ornamental plants. Its low numbers in California, contrasts reports that it was the most abundant and widely distributed of black scale parasitoids collected in 1937 in South Africa, Uganda, and Kenya (Compere 1940).

Neither *P. saissetiae* nor *A. saissetiae* were recovered in the 1984 to 1987 or 1988 to 1990 surveys. *Metaphycus inviscus* was not recovered in either the 1984 to 1987 or the 1988 to 1990 surveys. These findings differ somewhat from those of the 1979 to 1983 survey (during the release period) when *M. inviscus* was the only newly released parasitoid to show continued and strong evidence of establishment (Kennett 1986). *Metaphycus inviscus* is morphologically similar to *Metaphycus bartletti* Howard, a commonly collected parasitoid, and can be easily overlooked when large numbers of *M. bartletti* are present.

Abundance.—Relative to the other parasitoid species collected, both *P. probus*

Table 2. Rankings (in parenthesis) and percent total parasitiod abundance of primary and secondary parasitoids reared from black scale samples taken in Tehama, Madera, and Tulare County olive orchards between 1985 and 1987.

Species	Percent Parasitoid Abundance			Total
	Sacramento Valley	San Joaquin Valley		
	Tehama	Madera	Tulare	
Metaphycus bartletti[a]	42.9 (1)	27.1 (2)	51.9 (1)	43.2 (1)
Metaphycus helvolus[a]	25.6 (2)	48.7 (1)	35.4 (2)	29.2 (2)
Scutellista cyanea[a]	13.6 (3)	12.0 (3)	0.2 (10)	11.7 (3)
Coccophagus lycimnia[a,b]	4.1 (4)	5.3 (4)	7.9 (3)	4.8 (4)
Metaphycus zebratus[a]	3.6 (5)	1.1 (7)	0.4 (8)	3.1 (5)
Cheiloneurus inimicus[c]	3.2 (6)	1.5 (6)	0.6 (7)	2.7 (6)
Marietta mexicana[c]	2.2 (7)	3.6 (5)	0.6 (6)	2.2 (7)
Coccophagus ochraceous[a]	2.0 (8)	0.1 (10)	1.5 (5)	1.8 (8)
Coccophagus scutellaris[a,b]	1.7 (9)	0.2 (9)	2.7 (4)	1.7 (9)
Tetrastichus minutum[c]	0.9 (10)	0.6 (8)	0.2 (9)	0.8 (10)
Cheiloneurus noxius[c]	0.7 (11)	—	—	0.5 (11)
Prococcophagus probus[a]	0.7 (12)	—	—	0.5 (12)
Coccophagus rusti[a]	0.5 (13)	—	—	0.4 (13)
Metaphycus luteolus[a]	<0.1 (14)	—	—	<0.1 (14)
Moranila californica[a,c]	<0.1 (15)	—	—	<0.1 (15)
	$n = 8290$	$n = 936$	$n = 2469$	$n = 10,593$

[a] Primary parasitoids
[b] Males developed as a secondary parasitoid on some similar species
[c] Secondary parasitoid
[d] Only one specimen found.

and *C. rusti* were not common, ranking 12th and 13th and comprising only 0.5 and 0.4%, respectively, of the total parasitoids collected (Table 2). The most abundant parasitoids in the collections were *Metaphycus bartletti* Annecke & Mynhardt and *Metaphycus helvolus* (Compere). The widespread distribution and abundance of *M. bartletti* reveals its increasingly important economic role since its introduction (Kennett 1980). *Scutellista caerulea* (Fonscolombe) (= *Scutellista cyanea* Motschulsky) ranked third in abundance.

The remaining parasitoid species were found in low numbers, often sporadically in time and space. Together, *P. probus, C. rusti, Metaphycus luteolus* (Timberlake), and *Moranila californica* Howard comprised less than 1% of the total parasitoids recovered. *Metaphycus luteolus* may have been underrepresented because of their small number and close similarity to *M. bartletti.* Because only one specimen of *M. californica* was found, while a colony was kept at the Division of Biological Control insectary, contamination of the field emergence container may have occurred despite housings in separate buildings.

Metaphycus zebratus (Mercet), imported from Spain in 1985 and released from 1986 to 1988 (Daane & Caltagirone 1989), was recovered in Tehama, Madera, and Tulare Counties. It ranked fourth in parasitoid species collected, despite being released in large numbers in orchards being sampled. The parasitoid was recovered in lower numbers each subsequent year after releases were discontinued.

Distribution.—Greater diversity and abundance of parasitoid species were found in the Sacramento Valley than the San Joaquin Valley (Table 2), due, in part, to

differences in the synchronization of scale development found in the central valley. Cultural practices typically used in the San Joaquin Valley exacerbate climatic mortality and promote a more synchronous scale population than in the Sacramento Valley (Daane 1988). For *S. caerulea,* there is strong evidence that scale phenology is limiting in the species abundance. Although the third most commonly collected parasitoid in Tehama County, *S. caerulea* was rarely reared from black scale collected on olive in Tulare County. Moreover, it has been found in moderate numbers, in Tulare County, on oleander, where the scale has a less synchronous development pattern (D. Bromberger, personal communication). It is, therefore, not surprising that *P. probus* and *C. rusti,* as well as a number of lesser abundant primary and secondary parasitoids, were found in the Sacramento Valley rather than in the San Joaquin Valley.

Biology.—Documenting black scale parasitoid distribution and establishment in often difficult because of the low number of specimens recovered and the morphological similarity of other parasitoid species. Brief biological descriptions and morphological diagnoses of *P. probus* and *C. rusti* are provided because of the difficulty in identifying these two relatively unknown parasitoid species in California.

Prococcophagus probus was described by Annecke & Mynhardt (1979) as a solitary, primary parasitoid of black scale. Its reproductive biology is probably similar to that of *Prococcophagus varius* Silvestri & *P. saissetiae,* two black scale parasitoids that are morphologically very close to *P. probus.* In those species, both male and female are primary parasitoids, but the diploid female larva develops as an endoparasitoid, while the haploid male larva develops as an ectoparasitoid (Mazzone & Viggiani 1983). The validity of *Prococcophagus,* as a genus separate from *Coccophagus,* has been questioned by Mazzone & Viggiani (1984). Nevertheless, *Prococcophagus* can be distinguished from *Coccophagus* by its ventrally expanded antennal scape, laterally compressed funicle, and usually largely infuscated fore wings. The antennal scape of the female is more than twice as long as wide, with two dark streaks on the outer surface; the first antennal funicle segment is the longest, with rhinaria (Annecke & Mynhardt 1979). Superficially, *P. probus* is similar to *M. bartletti* in color and size. In samples with many parasitoids, misidentification can easily occur.

Coccophagus rusti is a solitary endoparasite of third instar and preovipositional adult black scale (Flanders 1952). The male is hyperparasitic, developing as a direct endoparasite of some primary parasitoids of black scale and other hosts. This species can also develop in soft brown scale, *Coccus hesperidum* L. (Compere 1940). *Coccophagus rusti* is easily distinguished from other black scale parasitoids by the following characters: the scutellum has three pairs of setae, the abdomen is entirely black, the thorax is yellow-brown, the pedicel is shorter than first funicle segment, and the forewing has an infuscation with a pale diagonal streak (Smith & Compere 1928). The male differs from the female, with its whole body black or brown-black (Annecke 1964).

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